An Integrated Load Planning Algorithm for Outbound Logistics at Webb Wheel

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Operations Management
Outline

• Webb Wheel Company Overview

• Problem Overview
  ▪ Motivation
  ▪ Challenges

• Analysis
  ▪ Solution Methodology
  ▪ Benchmark Analysis
  ▪ Decision Support Tool

• Conclusions and Recommendations
Webb Wheel

- Aftermarket products for trucks, trailers, and buses
- Over 500 product types
- **Products**
  - Brake Drums
  - Hubs
  - Spoke Wheels
  - Rotors
Webb Wheel

- Two plants
  - Cullman, AL
  - Siloam Springs, AR
- Geographically dispersed customer base
  - 4642 customers
  - Over 2400 unique zip codes
Problem Definition

- New orders are accepted from customers every day to be fulfilled within a certain lead time
  - Incomplete information about future orders
- Given inventory availability, loads are built daily and released based on various criteria:
  - Truck utilization and due date considerations
  - Order splitting is allowed
- Loads are shipped using common carriers and railroads:
  - Truck load, less-than-truck load, and intermodal containers.
- Each transportation mode has its own restrictions and cost structure.

Multi-item, Multi-mode, Heterogeneous VRP with split delivery, *incomplete information*, and other practical constraints
Main Goal

To develop an efficient *loading* and *routing* optimization model so that

- customer demand can be satisfied in a cost effective and timely manner
- higher truck utilization and route efficiencies are achieved

We propose

- an integrated model that
  - builds the loads for three transportation modes and
- dispatch them based on
  - Weight based utilization, Route-based utilization, or penalty policy.
Dispatch Policies

Truck Utilization (TU)
- Percentage of total weight in a truck to its capacity.

Route Utilization (RU)
- Percentage of total weighted distance to total ton-miles purchased in a route.

Penalty Policy (PP)
- Penalty of a route is the measure of its inefficiency:
  \[ PP = (1 - RU)(\text{Route Cost}) \]
# Webb Wheel’s Practice

<table>
<thead>
<tr>
<th></th>
<th>Miles</th>
<th>RU</th>
<th>PP</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW 1</td>
<td>485</td>
<td>63%</td>
<td>$414</td>
<td>$1,120</td>
</tr>
<tr>
<td>WW 2</td>
<td>522</td>
<td>64%</td>
<td>$433</td>
<td>$1,205</td>
</tr>
<tr>
<td>Total</td>
<td>1,007</td>
<td></td>
<td></td>
<td>$2,325</td>
</tr>
<tr>
<td>UA 1</td>
<td>522</td>
<td>90%</td>
<td>$120</td>
<td>$1,205</td>
</tr>
<tr>
<td>UA 2</td>
<td>193</td>
<td>87%</td>
<td>$48</td>
<td>$ 368</td>
</tr>
<tr>
<td>Total</td>
<td>715</td>
<td></td>
<td></td>
<td>$1,573</td>
</tr>
<tr>
<td>Savings</td>
<td>292</td>
<td></td>
<td></td>
<td>$ 752</td>
</tr>
<tr>
<td>Percent</td>
<td>28.9%</td>
<td></td>
<td></td>
<td>32.3%</td>
</tr>
</tbody>
</table>

---

![Map showing routes and distances]
Benefits

• Currently, there is no off-the shelf software to tackle this problem:
  ▪ Two employees of Webb Wheel manually build the loads.
• The tool *rations the limited inventory* over the critical orders.
• The tool provides an opportunity to *evaluate three transportation modes* in terms of
  ▪ Costs
  ▪ Capacities
  ▪ Other specific transportation mode restrictions
• The tool reports, in addition to total costs and cost allocations,
  ▪ *Truck and container utilization*
  ▪ *Route utilization and penalty*, novel measures for goodness of each route
Overall Approach

- Customer Orders
- Location
- Products
- Promise Dates

Graphical User Interface

- Optimization:
  - Assignment Problem
  - Routing Problem

- Reporting:
  - Load Breakdown
  - Route Breakdown

- Inventory
  - Products
Assignment Problem

• An extension of the Location-based Heuristic introduced by Bramel and Simchi-Levi (1995)

• $c_i$: cost of using seed location $i$
  - Cluster setup cost
  - Seed locations could be zip codes of order origination (TL and LTL) and ramp locations (for container/intermodal shipments)

• $a_{ij}$: cost of assigning customer order $j$ to seed location $i$

\[
Y_i = \begin{cases} 
1, & \text{if seed location } i \text{ is used,} \\
0, & \text{otherwise}, 
\end{cases}
\]

\[
Z_{ij} = \begin{cases} 
1, & \text{if customer order } j \text{ assigned to seed location } i, \\
0, & \text{otherwise}, 
\end{cases}
\]

\[
X_{ijp} = \text{amount of product } p \text{ shipped for customer order } j \text{ through seed location } i
\]
Objective function of the assignment problem

\[
\text{Min } \sum_{i \in I} c_i Y_i + \sum_{i \in I} \sum_{j \in J} a_{ij} Z_{ij}
\]

Cost Parameters For Each Transportation Mode:

<table>
<thead>
<tr>
<th></th>
<th>Seed Costs ((c_i))</th>
<th>Assignment Costs ((a_{ij}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trucks</strong></td>
<td>(s d_{0i} + m,)</td>
<td>(p_i + s (d_{0j} + d_{ji}) + m - c_i,)</td>
</tr>
<tr>
<td></td>
<td>((s + r_i) d_{0i},)</td>
<td>(p_i + (d_{0j} + d_{ji}) (s + r_i) - c_i,)</td>
</tr>
<tr>
<td></td>
<td>if (d_{0i} r_i \leq m,)</td>
<td>if (r_i (d_{0i} + d_{ji}) \leq m,)</td>
</tr>
<tr>
<td></td>
<td>otherwise,</td>
<td>otherwise,</td>
</tr>
<tr>
<td><strong>Containers</strong></td>
<td>(F_i)</td>
<td>(p_i)</td>
</tr>
<tr>
<td><strong>LTL</strong></td>
<td>(LTL_i(w_i, d_{0i}))</td>
<td>0</td>
</tr>
</tbody>
</table>
Challenges/Constraints

- Transportation related
  - Trucks:
    - Route cost
    - The Hook
    - Capacity issues
  - Containers:
    - Service time limit from the ramp location
    - Capacity issues
  - LTL:
    - Minimum charge
    - Piecewise linear cost function

- Inventory Related
  - Rationing limited inventory among critical orders
Inventory Constraint

Available Inventory:

Customer Orders:

**Customer#1:**
Demand: 3 units
Due Date: 10/25

**Customer#2:**
Demand: 3 units
Due Date: 10/10

**Customer#3:**
Demand: 1 unit
Due Date: 10/8
Routing Problem

- Given the clusters for TL, the drop sequence in a cluster is determined by a modified Traveling Salesman Problem (Dantzig (1963)).
- This is a Quadratic Integer Program since the route cost is determined by the transportation rate of the last drop location.
How to dispatch?

• Dispatch Rule 1: A combination of TU/RU
  ▪ If \( RU_i \geq (RU \text{ Cut off}) \) and \( TU_i \geq (TU \text{ Cut off}) \), dispatch route \( i \);
  ▪ Else, if \( RU_i + TU_i \geq (RU \text{ Cut off } + TU \text{ Cut off}) \), dispatch route \( i \);
  ▪ Otherwise, do not dispatch route \( i \).

• Dispatch Rule 2: Penalty-based
  ▪ If \( \text{Penalty}_i \leq (\text{Penalty Cut off}) \), dispatch route \( i \); otherwise, do not dispatch.

• What if there is a late order?
  Two late order dispatch evaluation methods:
  1. Direct Cost Comparison (DC): *Compare the cost of LTL to the total cost of route*.
  2. Cost Per Pound Comparison (CPP): *Compare cost per pound for LTL shipments to cost per pound of the route cost*
## Benchmark Analysis

### Cullman Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Weight Shipped</th>
<th>Total Cost</th>
<th># of Shipments</th>
<th>Cost per Pound</th>
<th>% Savings</th>
<th>Late Orders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webb Wheel</td>
<td>19,347,373</td>
<td>$1,000,000</td>
<td>539</td>
<td>5.17¢</td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>ILR</td>
<td>19,316,139</td>
<td>$1,004,029</td>
<td>488</td>
<td>5.19¢</td>
<td>-0.57%</td>
<td>11</td>
</tr>
<tr>
<td>Relaxed ILR</td>
<td>19,019,865</td>
<td>$971,867</td>
<td></td>
<td>5.11¢</td>
<td></td>
<td>136</td>
</tr>
</tbody>
</table>
Benchmark Analysis

The source of the savings:

- ILR
- Relaxed ILR
- DD ILR Relaxed
- TC ILR Relaxed

Transportation modes:

- WW
- ILR
- Relaxed ILR

Legend:
- LTL
- IM
- TL
Benchmark Analysis

Siloam Springs Results:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Weight Shipped</th>
<th>Total Cost</th>
<th># of Shipments</th>
<th>Cost per Pound</th>
<th>% Savings</th>
<th>Late Orders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webb Wheel</td>
<td>11,059,357</td>
<td>$750,000</td>
<td>327</td>
<td>6.78¢</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>ILR</td>
<td>10,996,688</td>
<td>$730,700</td>
<td>265</td>
<td>6.64¢</td>
<td>2.02%</td>
<td>3</td>
</tr>
<tr>
<td>Relaxed ILR</td>
<td>10,908,633</td>
<td>$703,344</td>
<td>270</td>
<td>6.45¢</td>
<td>4.93%</td>
<td>63</td>
</tr>
</tbody>
</table>

- **Important differences between Siloam Springs and Cullman**
  - Siloam Springs serves a larger, but less populated area.
    - Easier to find efficient routes for a smaller, densely populated region
  - The number of orders from Cullman is larger than Siloam Springs.
    - Easier to identify consolidation opportunities for Cullman, even manually.
### Route Breakdown Report

#### Route 1
- **Route Cost**: $2,586.41
- **Miles**: 1,131.0
- **Total Weight**: 43,650
- **Truck Utilization**: 100.3%
- **Route Efficiency**: 67.2%
- **Penalty**: $848.34
- **Warehouse**: Cullman
- **Mode**: Truck
- **Carrier**: Carrier 1

<table>
<thead>
<tr>
<th>Drop</th>
<th>Order</th>
<th>Promise Date</th>
<th>Weight (lbs.)</th>
<th>Customer</th>
<th>City</th>
<th>State</th>
<th>Zip Code</th>
<th>Drop Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>115041</td>
<td>12/21/2012</td>
<td>2,224</td>
<td>Customer 877</td>
<td>CHATTANOOGA</td>
<td>TN</td>
<td>12345</td>
<td>$45.70</td>
</tr>
<tr>
<td>2</td>
<td>115089</td>
<td>12/21/2012</td>
<td>6,849</td>
<td>Customer 229</td>
<td>CARLISLE</td>
<td>PA</td>
<td>12345</td>
<td>$412.38</td>
</tr>
<tr>
<td>3</td>
<td>115134</td>
<td>12/21/2012</td>
<td>89</td>
<td>Customer 266</td>
<td>BETHLEHEM</td>
<td>PA</td>
<td>12345</td>
<td>$30.73</td>
</tr>
<tr>
<td>4</td>
<td>115131</td>
<td>12/21/2012</td>
<td>5,805</td>
<td>Customer 294</td>
<td>BENSEALEM</td>
<td>PA</td>
<td>12345</td>
<td>$411.55</td>
</tr>
<tr>
<td>5</td>
<td>115132</td>
<td>12/21/2012</td>
<td>4,218</td>
<td>Customer 295</td>
<td>BENSEALEM</td>
<td>PA</td>
<td>12345</td>
<td>$305.88</td>
</tr>
<tr>
<td>6</td>
<td>115197</td>
<td>1/2/2013</td>
<td>6,730</td>
<td>Customer 342</td>
<td>TUXEDO</td>
<td>MD</td>
<td>12345</td>
<td>$396.41</td>
</tr>
<tr>
<td>7</td>
<td>114911</td>
<td>12/21/2012</td>
<td>6,673</td>
<td>Customer 329</td>
<td>CHANTILLY</td>
<td>VA</td>
<td>12345</td>
<td>$379.34</td>
</tr>
<tr>
<td>8</td>
<td>115049</td>
<td>12/21/2012</td>
<td>4,218</td>
<td>Customer 326</td>
<td>MANASSAS</td>
<td>VA</td>
<td>12345</td>
<td>$245.93</td>
</tr>
<tr>
<td>9</td>
<td>115047</td>
<td>12/21/2012</td>
<td>6,844</td>
<td>Customer 325</td>
<td>MANASSAS</td>
<td>VA</td>
<td>12345</td>
<td>$358.49</td>
</tr>
</tbody>
</table>

#### Route 3
## Load Breakdown Report

### Route 1

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Route Cost</td>
<td>$2,586.41</td>
<td>Truck Utilization</td>
<td>100.3%</td>
<td>Warehouse</td>
<td>Cullman</td>
</tr>
<tr>
<td>Miles:</td>
<td>1,131</td>
<td>Route Efficiency</td>
<td>67.2%</td>
<td>Mode</td>
<td>Truck</td>
</tr>
<tr>
<td>Total Weight:</td>
<td>43,650</td>
<td>Penalty:</td>
<td>$848.34</td>
<td>Carrier</td>
<td>Carrier 1</td>
</tr>
</tbody>
</table>

#### Drop 1

Customer 877, Address 877, TN 12345

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Qty this Shipment</th>
<th>Qty Ordered</th>
<th>Qty Shipped</th>
<th>Qty Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>61527B</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>61951B</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>65151B</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>65179B</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>66353B20</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>66864F20</td>
<td>20</td>
<td>40</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

#### Drop 2

Customer 229, Address 229, PA 12345

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Qty this Shipment</th>
<th>Qty Ordered</th>
<th>Qty Shipped</th>
<th>Qty Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>66854B20</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
The Challenges of the Project

Effective Decision Making

Effectiveness = Quality \times \text{Acceptance}

By Jerry Allyne
Vice President, Strategic Planning & Analysis
Boeing Commercial Airplanes

*From the 2013 Informs Analytics Conference*
Current Picture

- WW continues to use our decision support tool.
- As of two weeks ago, they reported an average of 4.4% savings in their annual outbound logistics costs.
We develop a 2-stage heuristic to determine the daily load planning and routing plans. New route evaluation measure, route efficiency is described for the first time, and used in dispatching the daily routes. Heuristic provides good quality solutions. The quality of solutions are dependent on
- Geographical distribution of orders,
- Order consolidation opportunities,
- Deadline restrictions, and
- Inventory availability.

Future Work
- Improvement heuristics to handle late orders
- Allocation of orders to Siloam Springs and Cullman simultaneously.
Questions?